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# Importance of oceanic decadal trends and westerly wind bursts for forecasting El Niño

by

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**Abstract.** The **sea level interannual variations** observed in the tropical Pacific over the period 1980-1998 show some strong asymmetry with respect to the equator. Between 1984 and 1990, the ocean contains heat in excess in the North and in deficit in the South. This anti symmetry is successfully reproduced by a coupled ocean-atmosphere model which has skill in **forecasting** warm and cold events with one-year lead over this period. The South exhibits a regular trend of heat accumulation since 1984 up to 1997 and the whole tropical Pacific heat content is larger in 1980-1982 and 1996-1997 than in any other year. In order to succeed in predicting the 1982-1983 and the 1997-1998 **El Niño** events one year in advance, the model needs the combination of this oceanic heat charge and the westerly wind bursts that irregularly show up in the western Pacific.

ocean-atmosphere interaction
global climate changes

## Background

The last twenty years have seen two El Niño warm events which were among the strongest on record. With the Tropical Ocean Global Atmosphere program (TOGA), observation systems have blossomed, including the implementation of *in situ* measurements and the launch of satellites for oceanography. As illustrated for the last big event (McPhaden, 1999), these data allow to monitor the seasonal to interannual changes of our climate. Although considerable progress has also been done in simulating the oceanic and atmospheric interannual variability with numerical models, predicting a warm event one year in advance is still a big challenge. All the coupled ocean-atmosphere systems available for forecasting failed to predict the last El Niño (for a review, see Barnston et al, 1999). Wyrtki (1985) highlighted that monitoring the slow water displacements in the western Pacific can provide some insight on the likelihood of a coming warm event. At the same time, Barnett (1984) suggested that the rapid changes of surface winds over the Indonesian region, known as **Westerly Wind Bursts (WWB)**, play a role in **ENSO (El Niño Southern Oscillation)**. With the end of the TOGA program, it became clear that the ocean beyond the equatorial regions should no longer be neglected, because their slow variability influence

ENSO (Gu and Philander, 1997). We examine here the signals in these two frequency domains by using observations over the period 1980-1998 and investigate the role both play in ENSO by giving examples of model forecasts.

**Off-equatorial ocean**

Sea level variations relative to their climatology over January 1980- December 1996 have been estimated using a combination of hydrographic measurements and TOPEX-Poseidon satellite data (see Perigaud et al, 1999 for details). These data show that the North tropical Pacific does not vary at all like the South (Fig. 1a). Indeed the period 1984 to 1992 exhibits a marked anti symmetry. Vertical bars on this figure indicate the dates when the El Niño events reach their warm peak phases, peaks being defined by the maxima of the observed Niño3 SST index, i.e. the average of the Sea Surface Temperature in the eastern equatorial Pacific. Apart from this striking North/South anti symmetry, this figure does not give evidence for any scenario involving the off-equatorial ocean that systematically happens at a particular phase of the El Niño events. It is rather striking that each of the four warm events considered here exhibits some uniqueness. The South undergoes a regular increase of heat between 1984 and 1997. The situation prior to 1982 is quite different from the one prior to 1996, with opposite signs in the North. These observed signals can be trusted even during the non satellite period prior to 1992, because they have been validated with independent sources of data (Florenchie et al, 1999).

Oceanic and atmospheric data have been used in (Dewitte and Perigaud, 1996) to define new parameterizations of a coupled ocean-atmosphere model based on the equations described in Zebiak and Cane (1987). Studying the mechanisms involved in the oscillations reproduced during thirty-year long experiments leads to replace the Gill (1980) model component by a statistical atmosphere and shows that then, the coupled model successfully reproduces the observed variations of both the meridional and zonal components of the wind (see Cassou and Perigaud, 1999). In particular, it is found that the oscillatory regime is dependent on the wind and ocean variability beyond 5° of latitude. Systematically after each warm peak, the North gets recharged in heat and the South discharged (Fig. 1b). The North/South anti symmetry is explained as follows. Because the warm peaks are associated with a southward migration of the Inter Tropical Convergence Zone, the meridional component of the wind is responsible for an anticyclonic curl beyond 5°N and is associated with the recharge of the North. Because the meridional wind South of 5°S has relatively little contribution while the equatorial westerlies associated with warm events weaken with increasing distance from the equator, the curl beyond 5°S is cyclonic and explains the heat discharge in the South. Consistently with the model, it is found in the observations that the asymmetry of the wind components with respect to the equator is associated with the anti symmetric part of the sea level signals shown in Fig. 1a.

The coupled model initialized from realistic oceanic and atmospheric conditions is used to generate series of two-year long forecasts over the 1980-1998 period (see Perigaud et al, 1999). As illustrated in Figure 2, the model successfully predicts the observed Niño3 SST indices with one-year lead over the period 1984-1993. Detailed validation of the forecasts with data over this period indicates that the model is also skilled for predicting the sea level, the two wind components and the SST anomalies over the whole tropical Pacific. In addition, this success is robust. Forecasts are similarly good, whether the model is initialized with sea level, wind or SST observations, with a combination of them, or with the data-model nudging applied in Chen et al (1995). They are not much modified either when model parameterizations are changed within reasonable ranges. This success is explained by the fact that the data-free-model coupled behavior depends on anomalies in the equatorial and off-equatorial domains that resemble the ones observed during this period.

By contrast, the model fails to predict the warm events of 1982-1983 and 1997-1998 one year in advance. Because these two events are particularly strong, forecast tests were performed with the model parameterizations changed in order to put the model in a regime of stronger oscillations. Similarly, experiments were performed with air-sea latent heat exchanges added into the model, because warm events are associated with a trade winds weakening that reduces evaporation and helps their growth. None ot these tests brought significant progress in forecasting. Moreover, tests were performed after improving the initial conditions of the ocean by using sea level data. These conditions were improved mostly beyond 5° of latitude and contain, in particular, the decadal trends presented in Figure 1a. This initial success is quite different from Chen et al (1998) where sea level observations are used to initialize the equatorial ocean only. However, it does not help improve the forecasts. In all tests, the model does not predict the 1982 warm growth for initial conditions prior to May 1982. Similarly, it fails to predict the last El Niño event prior to March 1997. It is concluded that something fundamental besides the off-equatorial oceanic heat content is missing in the model.

## Westerly Wind Bursts (WWB)

The largest misfit between the observed and simulated winds is located in the western Pacific. Indeed this region is subject to a strong variability at relatively high-frequencies with the occurrence of WWB.Such frequencies are certainly well observed from satellite scatterometry (Liu et al, 1995). As illustrated in Figure 3a, WWB are also detectable from the monthly averaged ship data analysis provided by Florida State University (Goldenberg and O'Brien, 1981). This figure presents the time series of the WWB index (i.e the average of the zonal wind stress anomalies over the western Pacific). The index varies very irregularly from month to month. Note that WWB are not detectable from the "detrended" version of the winds used to initialize the Zebiak and Cane (1987) model before delivering their standard or improved series of forecasts (Chen et al, 1995; 1998). The index of the "detrended" winds stays weak and varies smoothly. In the "non-detrended" winds, WWB are found in winter more often than in summer. It is unusual to find them during winters of El Niño years, but November 1986 is a case when there was a strong WWB although the warm event was already well developed. For the sake of simplicity here, we retain as WWB the wind anomalies which have an index larger than 0.025 Pa (i.e. the horizontal bar on Fig. 3a). The individual WWB cases that are thus selected correspond to a wide variety of patterns showing that the center of action can be located in the western Pacific, North, South or along the equator. On average (Fig. 3b), WWB have a strong eastward component along the equator with values reaching 0.04 Pa.

Because the atmospheric component of the model lacks variability West of the dateline, introducing some parameterization of WWB in the model appears to be a necessary ingredient to improve the simulations. This is achieved by adding to the atmospheric model component the WWB pattern presented in Fig. 3b multiplied by a factor varying in time which is *a priori* prescribed. The whole difficulty lies in defining this time factor, the predictability of WWB being highly uncertain. It is tempting to say that WWB are the strongest during the winters preceding strong El Niño events, but Fig. 3a indicates that this is not always a valid relationship (the horizontal bar on this figure also corresponds to the 1°C level). Winter 1990-91 did not have strong WWB, neither did winter 1985-86. The time factor cannot be dependent either on local characteristics of the warm pool because neither its SST nor its sea level anomalies are strongly correlated with the WWB index.

The coupled model is now used to test the sensitivity of forecasts to WWB with a time factor which is non-zero only during winter months (November to March) and only when the WWB index is larger than 0.025 Pa, i.e. during the winters 1981-82, 1982-83, 1986-87, 1989-90, 1990-91 and 1996-97. The cases presented here were all obtained for a time factor equal to 1 continuously applied during the 3 months of November, December and January. In reality, individual WWB are stronger than in Fig. 3b, but last less than 3 months. Tests have been done with other combinations of amplitude and duration. The sole objective here is to investigate whether the coupled model is sensitive to WWB or not.

The 1981-83 and 1996-98 forecasts delivered by the model in the standard configuration (initialization with wind only) are presented as a reference of the model performance without the WWB implementation (Fig. 4ab). Figure 4cd presents the results when the sea level data have been used to improve the oceanic initial conditions and when the WWB pattern is applied during the 3 months of winter 1980-81 or 1996-1997 as explained above. The model then predicts a realistic warm growth. Applying the WWB pattern in winter 1982-83 or 1986-87 does not degrade the predicted warm decays (not shown), because the western Pacific which is responsible for the reversal of the warm growth, is already a cold reservoir then. Similarly, when applied in winter 1989-90 or 1990-91, it does not predict erroneous anomalies in 1991, because most of the equatorial and South Pacific is cold and the North is quasi normal then (see Fig. 1a). Finally, note that for the same WWB applied to the model, the warm event predicted in winter 1981-82 is weaker than the one predicted in winter 1996-97. These results can be enlightened below by the comparison with the signal of heat content in the whole tropical Pacific ocean.

**Relationship between WWB and Oceanic Heat Charge (OHC)**

The OHC index is defined as the average of sea level in the tropical Pacific between 15°S and 15°N. The North and South signals presented in Fig. 1a added to the equatorial contribution (weighed by their respective surface) give the OHC. It is striking that the observed OHC has varied very slowly since 1980 (Figure 5). The period between 1983 and 1995 contrasts with the 1980-1982 and the 1996-1997 years. The latter exhibit a significant heat excess. It is shown in (Perigaud and Florenchie, to be submitted) that this signal is related to the atmospheric and oceanic conditions over the Indian and Pacific regions between 30°S and 30°N. Here this signal is proposed as a measure of the degree to which the WWB are active in the coupled system. The forecast cases described above indicate that below the +1cm level for the OHC, the WWB have very little impact on the predictions. The greater warm growth in the 1996-97 case compared to the 1981-82 case is consistent with the stronger OHC index of the model initialized in 1996. Even if the relationship is certainly not linear, results indicate that there is a possible link between the

OHC and the ability of WWBs to trigger warm events. Because the OHC varies at a much lower frequency than WWB, it could be used in a forecast context as an index of likelihood for a coming warm event.

## Discussion

Results presented above are certainly dependent on the model and its parameterizations. Nevertheless, they are robust, because the forecast outputs have been thoroughly validated with data (see Perigaud et al, 1999) and the reader can be certain that the predictive success mentioned here is not based on the SST Niño3 index only. In addition, the experiments performed without the WWB were many more than the ones reported here and all failed to predict the two big warm events, or had successful Niño3 SST predictions but some flaws in the associated oceanic or atmospheric predicted anomalies. Finally, the success with WWB appears robust, because the forecasts remain good for other choices of time factors (amplitudes ranging between 0.5 and 1.5, duration ranging between 2 and 4 months, or intermittently set to 1. over 6 months).

Observations show an amazingly rich variability both in low and high frequencies. Although the decay of heat content in the North and the increase in the South are fairly regular since 1983, the situation in 1997-98 has little to do with that in 1982-83. Because the coupled ocean-atmosphere model used here is based on simplified physics, it cannot reproduce the wide spectrum of observed variability. Even when the ocean model is well initialized with sea level assimilation and when the WWB statistical pattern is added to the atmospheric component as proposed above, this system is not a valid one for predictions, but only an interesting tool for testing ideas. Results of experimenting this tool lead to the following message. WWB have an impact on the coupled system in its ability to grow a warm event that depends on the oceanic heat content of the whole tropical Pacific. In addition to monitor the oceanic heat content of the western Pacific as a possible precursor of El Niño, it is thus worth to monitor the OHC over the whole tropical Pacific within a 1 cm accuracy. In the present study, only years 1992 to 1998 are covered with such a good accuracy. Prior to 1992, we know that the results are valid enough to confirm this message, because the sea level anomalies over the period 1980-1992 are consistent with independent observations of sea level over the Indian Ocean and winds over both oceans (see Perigaud and Florenchie, to be submitted). If the estimates prior to 1991 had the accuracy of TOPEX-Poseidon, it would be worth refining this study to find new wonders in the variability of Nature and demonstrate how every little detail counts in a coupled system like our climate.

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**Figure Caption**:

**Figure 1**. Variations as a function of time of sea level anomalies averaged over all longitudes in the Pacific (130°E-80°W) between 5° and 15° of latitude North (solid line) or South (dashed line). Top panel corresponds to observations between January 1980 and July 1998, bottom panel to model simulations extracted from 30-year long coupled experiments. In each panel, the vertical bars indicate the peaks of the Niño3 SST index (90°W-150°W, 5°S-5°N).

**Figure 2**. SST Niño3 indices derived from observations (solid), from model initial conditions (dashed) or predictions (dotted) as a function of time for various two-year long periods indicated in the title of each panel.

**Figure 3**. Westerly Wind Burst index and spatial pattern. Top panel presents the time series of the WWB index (solid), i.e. the average of the zonal wind stress over the western Pacific (130°E-180°E; 12°S-12°N), and the SST Niño3 index (dotted).Scales for WWB in Pascal and SST in Degree Celsius are given on the left and right axis respectively. The bottom map with isocontours of 0.01 Pa is the average of the zonal wind stress fields that have a WWB index larger than 0.025 Pa (negative values are put to zero).

**Figure 4**. Same as Fig.2 for the 1981-1983 and 1996-1998 cases. For the forecasts, the WWB pattern is applied systematically during winters (between November and January) as described in the text.

**Figure 5**. Variations of the observed Oceanic Heat Content (solid) and WWB (dotted) indices between January 1980 and July 1998. The OHC is the average of sea level over the whole tropical Pacific (130°E-80°W, 15°S-15°N). Scales for OHC in cm and WWB in Pa are given on the left and right axis respectively.

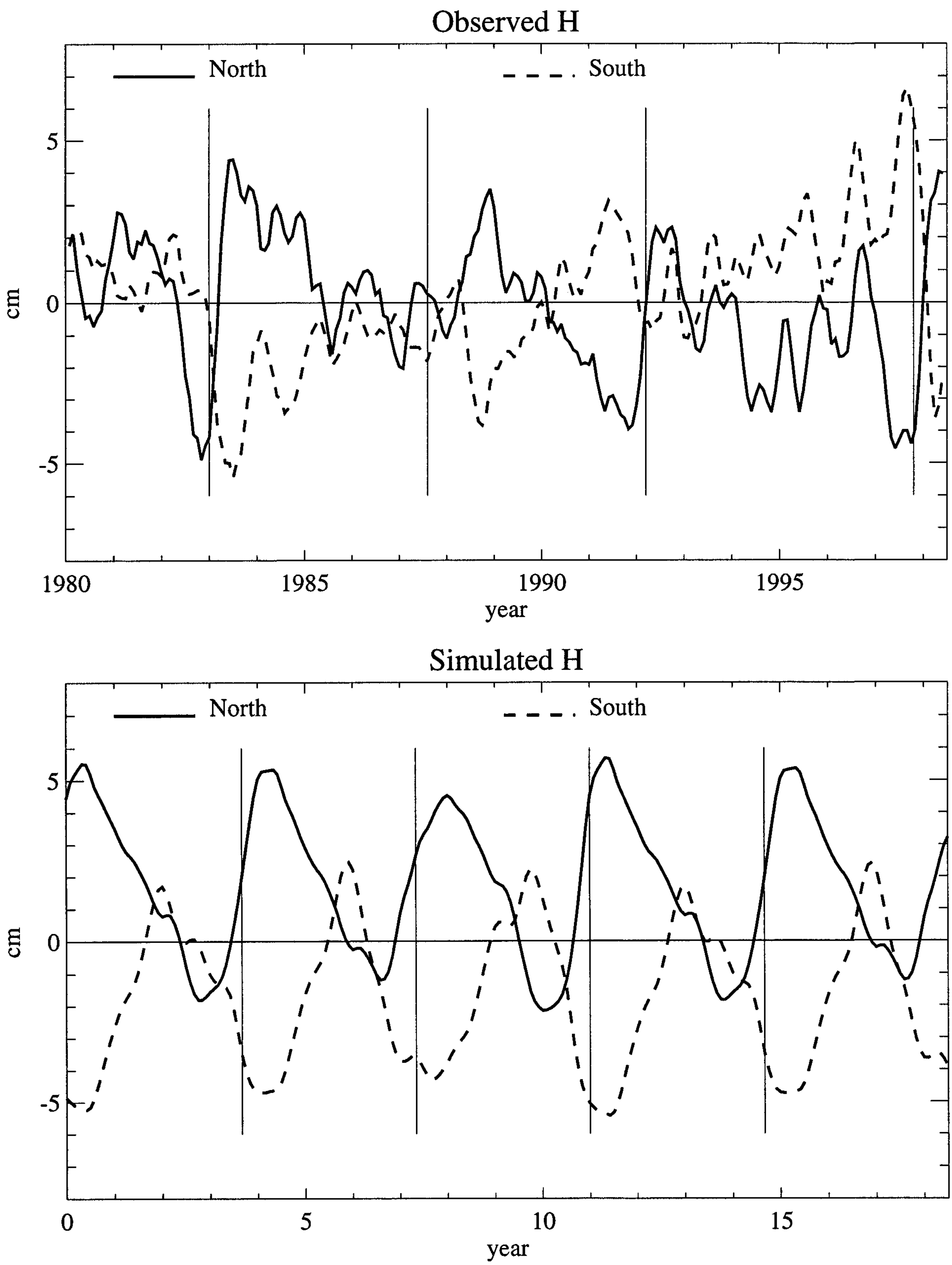

Observed H
North
South
cm
5
0
-5
1980
1985
1990
1995
year
Simulated H
North
South
cm
5
0
-5
0
5
10
15
year

Fig. 1

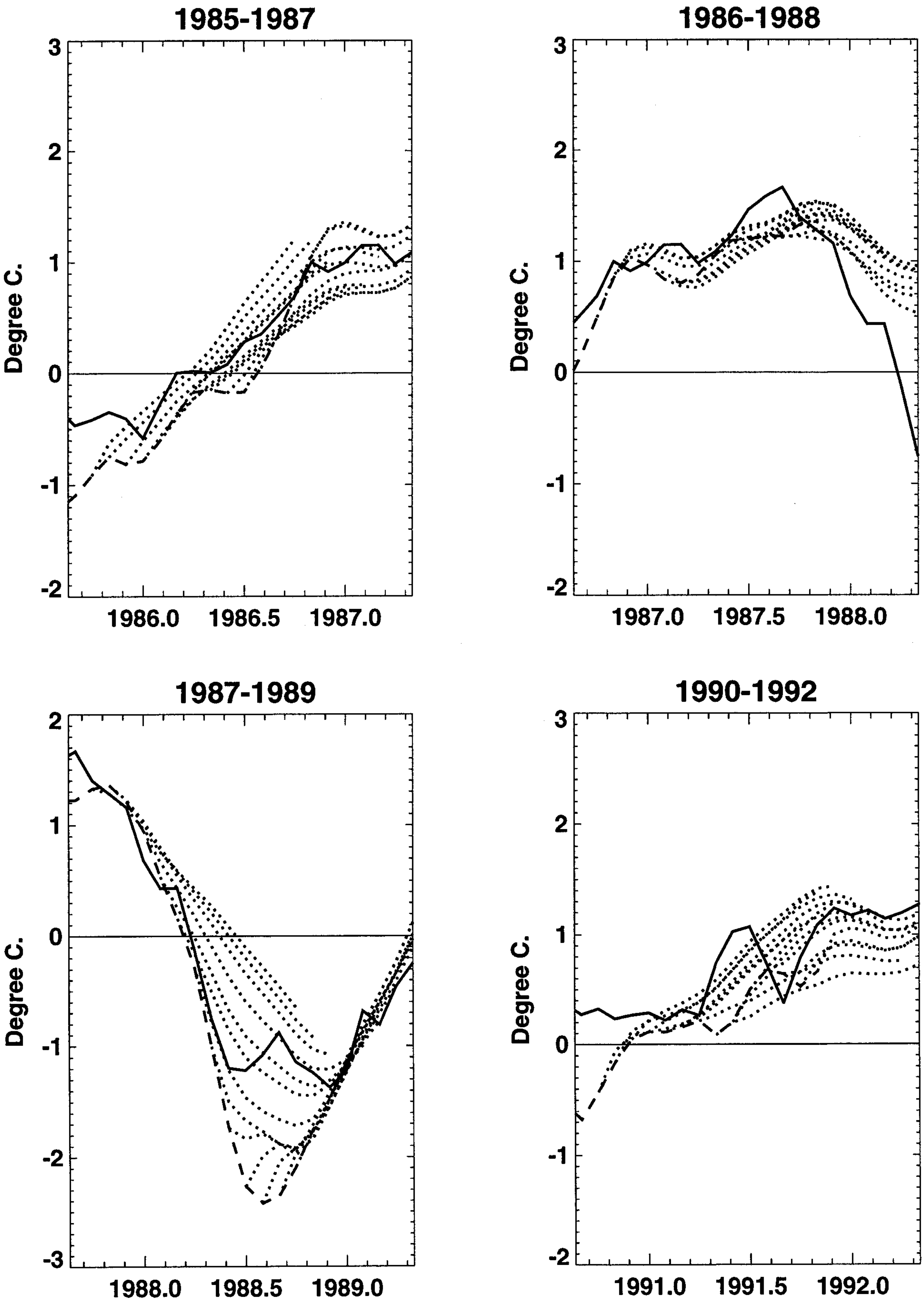
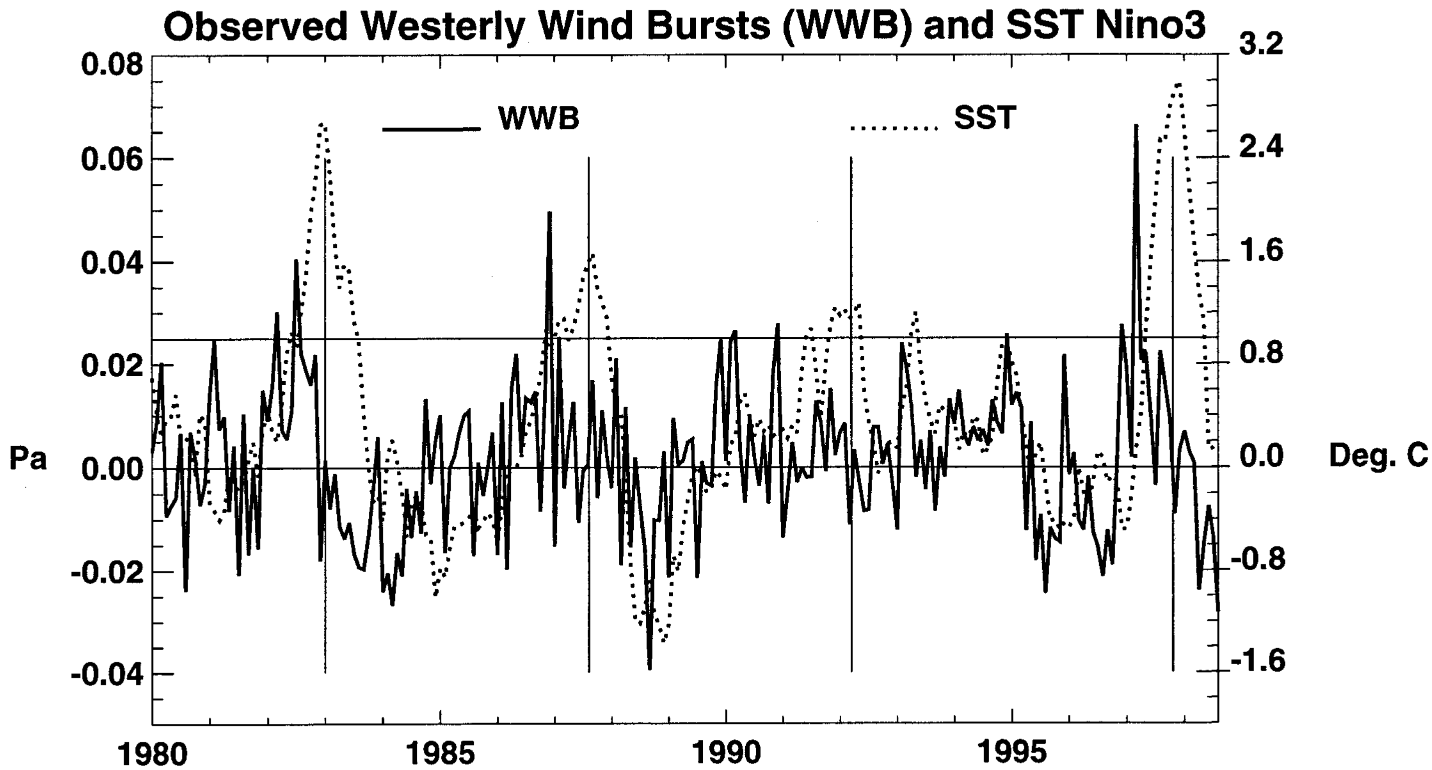
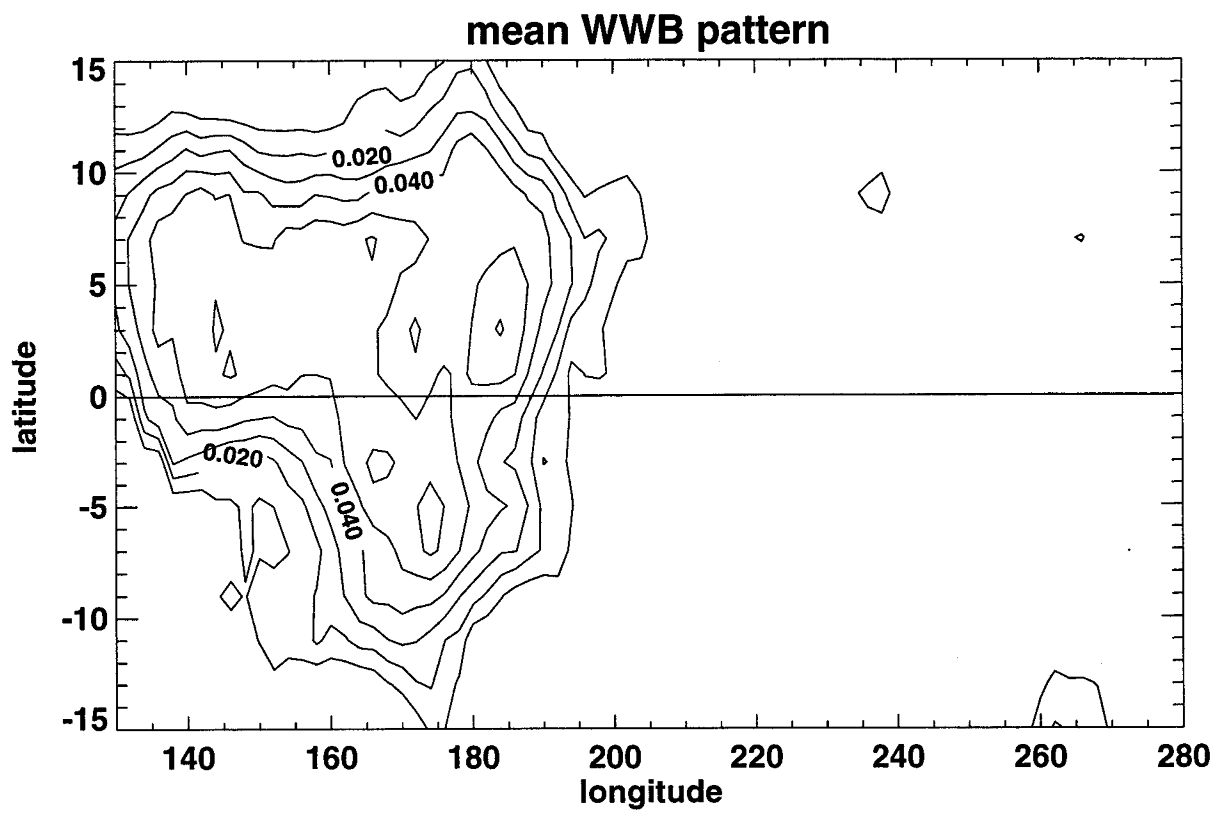

1985-1987
1986-1988
1987-1989
1990-1992
Degree C.
3
2
1
0
-1
-2
-3
1986.0
1986.5
1987.0
1987.5
1988.0
1988.5
1989.0
1991.0
1991.5
1992.0

Fig. 2



Observed Westerly Wind Bursts (WWB) and SST Nino3
WWB
SST
Pa
Deg. C
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
3.2
2.4
1.6
0.8
0.0
-0.8
-1.6
1980
1985
1990
1995

mean WWB pattern
0.020
0.040
0.020
0.040
latitude
longitude
15
10
5
0
-5
-10
-15
140
160
180
200
220
240
260
280


Fig. 3

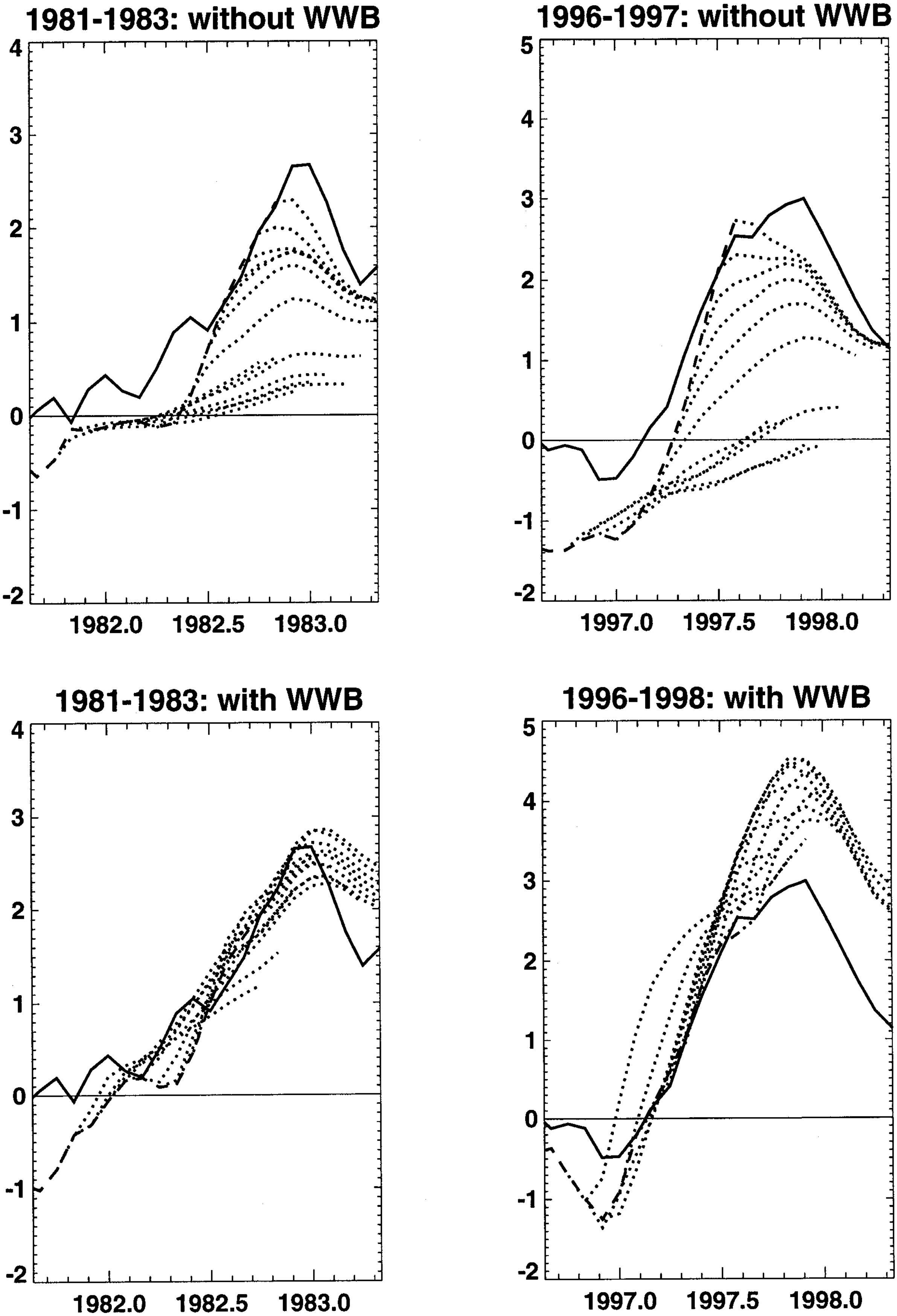

1981-1983: without WWB
1996-1997: without WWB
1981-1983: with WWB
1996-1998: with WWB
4
3
2
1
0
-1
-2
5
1982.0
1982.5
1983.0
1997.0
1997.5
1998.0

Fig. 4

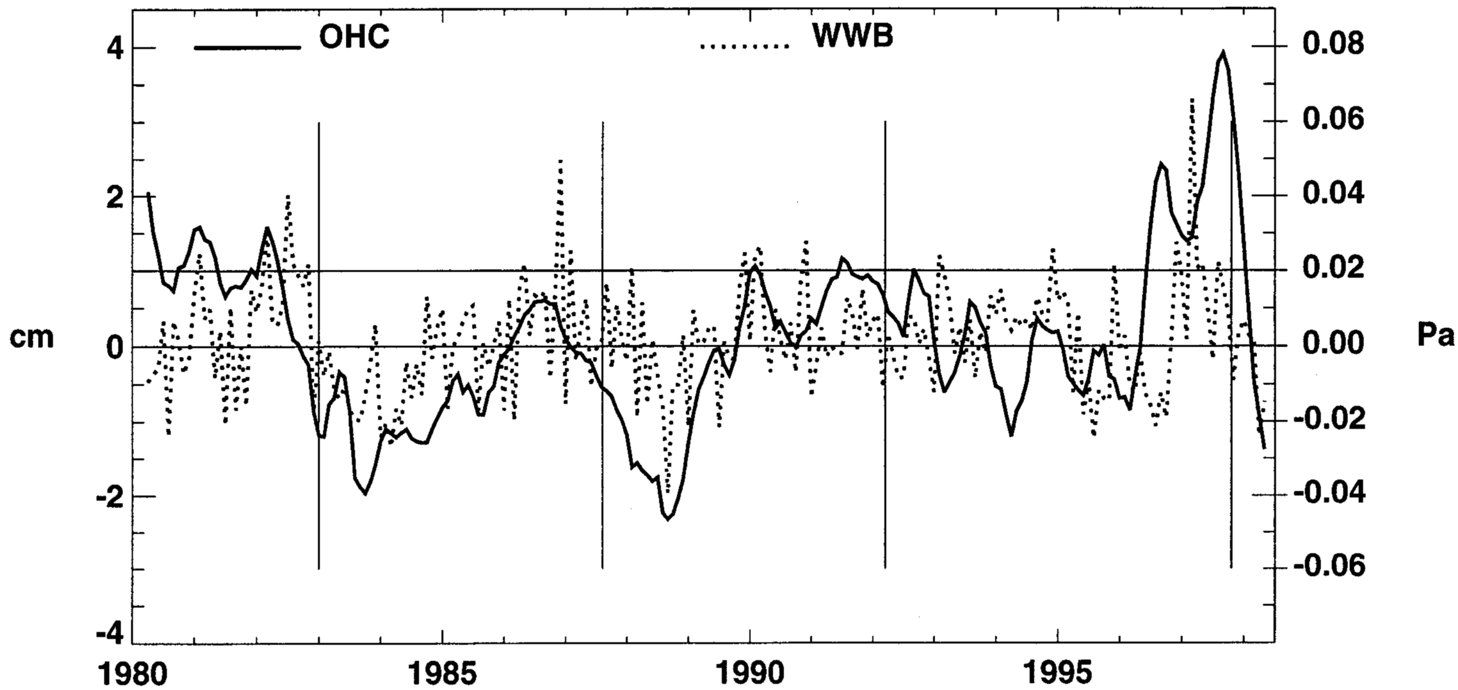

OHC
WWB
4
2
0
-2
-4
cm
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
Pa
1980
1985
1990
1995

Fig. 5